Hydrography of the Dutch Wadden Sea

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SUMMARY

In this paper an attempt has been made to describe for the Dutch Wadden Sea water movement, transport of suspended matter and the cycle of suspended organic matter. Stress has been laid on the fact that these are related subjects, which therefore ought to be studied in combination. The discussion was based on observations made in the years 1949–1951 in the southwestern part of the area. A summary of the figures found from these observations is given in table 23.

TABLE 23

Comparison of average data for the North Sea, about 15 km outside the tidal inlet, with data for the Wadden Sea (Marsdiep area).

	North Sea	*Wadden Sea*
Chlorinity, $^0/_{00}$	18	16 (9-17)
Salinity, $^0/_{00}$	32	29 (16-31)
Suspended silt, mg/l	6	18
Suspended sand, mg/l	—	5
Total suspended matter, mg/l	–	23
Organic matter, summer, mg/l	1.5	4
Organic matter, winter, mg/l	—	1
Organic matter, average, mg/l	–	2.5
Phosphate, summer, μg-at/l	0.05-traces	0.10-traces
Phospate, winter, μg-at/l	0.60	0.75
Phosphate, average, μg-at/l	0.31	0.49
Dissolved organic P, summer, μg-at/l	0.60	0.80
Dissolved organic P, winter, μg-at/l	0.20	0.30
Dissolved organic P, average, μg-at/l	0.38	0.53
Total dissolved P, average, μg-at/l	0.69	1.02
Particulate P, average, μg-at/l	0.25	0.60
Total P, average, μg-at/l	0.94	1.62
Chlorophyll, summer, mg/m^3	—	30
Chlorophyll, winter, mg/m^3	—	3
Chlorophyll, average, mg/m^3	—	13

For a good understanding of the results two facts appear to be of primary importance. First, there is a considerable exchange of water between Wadden Sea and North Sea, which is constantly at work to change Wadden Sea conditions, so that they approach those of the North Sea. Secondly, the concentration of light suspended material (silt) and of suspended organic matter is, notwithstanding this exchange, constantly higher in the Wadden Sea than in the North Sea.

1. *Water movement* (Chapter II).

In the southwestern Wadden Sea the vertical salinity gradient is only slight and the transport of fresh water is therefore mainly the result of

tidal mixing, while transport as a result of differences in density plays only a minor part. The mixing processes are greatly stimulated by differences in water movement between channels and tidal flats.

The rate of the exchange of water between Wadden Sea and North Sea resulting from these mixing processes was determined from the distribution of fresh water, which in its turn could be found from salinity figures. The average quantity of fresh water present in the area studied is 13 times the average amount discharged from the IJsselmeer during one tide. Therefore in every tidal period 8% of the total quantity of fresh water present within the Wadden Sea is transported to the North Sea. This percentage can be applied to every dissolved substance that has the same distribution as the fresh water.

A simple empirical method was developed to calculate the water exchange in a well-mixed estuary by means of a segmentation method. The figures calculated by means of this method for the amounts of fresh water present in the area studied were found to exhibit a significant correlation with those calculated from the salinity distribution.

2. *Suspended matter* (Chapter III)

Observations throughout a full tidal period at fixed stations and in distinct water masses marked by floats provided the basis for the study of suspended matter. The material was divided into two fractions, called "sand" and "silt", separated at a grain size of about 50 μ.

The amount of material in suspension varies with current velocity. There is a time lag varying from a few minutes to one hour between the turn of the tide and the moment at which the minimum concentration of suspended matter is measured.

Large amounts of suspended matter are transported forth and back by the tidal streams; the total quantity of silt transported in every tidal phase through the Marsdiep amounts to 8×10^6 kg of dry weight. There is no conclusive evidence of a residual transport of silt in one direction or the other.

Although no substantial quantities of silt are supplied to the area by the IJsselmeer or by internal abrasion, the concentration of suspended silt is maintained at a higher level in the Wadden Sea than in the North Sea. The increase of the quantity of suspended silt inward is gradual and runs parallel with an increase in the silt content of the bottom.

The higher concentration of suspended silt in the Wadden Sea as compared with the North Sea is supposed to be caused by an accumulation mechanism resulting from a progressive decrease in water movement (especially a decrease in mean current velocity) from the outer to the inner part. The concentration actually observed is thought to

be the result of the balance maintained between this accumulation and the loss of silt through water exchange. The mechanism does not prevent the loss of dissolved substances.

3. *Organic matter.*

The cycle of organic matter was studied by determining the quantities of organic matter present, and computing the phosphorus content of water and organic material. The phosphorus is partly present as particulate P, partly as dissolved P. The particulate P is for the greater part contained in organic matter, while the dissolved P consists partly of organic P, partly of phosphate.

The quantities of organic matter, as well as those of the phosphorus components, are subject to annual variations. The largest quantities of organic matter and organic P (particulate as well as dissolved) are found in summer, whereas phosphate attains its maximum in winter.

The concentration of suspended organic matter (as well as suspended P) parallels the concentration of suspended silt and is therefore higher in the Wadden Sea than in the North Sea. It is supposed that the reason for this high concentration is the same as for the high concentration of suspended silt.

The concentration of dissolved P is also, though only slightly, higher in the Wadden Sea than in the North Sea. Since dissolved substances are exchanged freely, this causes a residual transport of dissolved P to the latter area. In every tidal period a net amount of 2400 kg of dissolved P is supposed to be transported to the North Sea. Fresh water from the harbour of Den Helder contributes to this quantity to the extent of about 500 mg/tide; the IJsselmeer, however, does not contribute to this amount, since the phosphorus concentration of the fresh water from this source is too low. The loss of the remaining 1900 kg of dissolved phosphorus is probably neutralized by the transport of the same amount of particulate organic phosphorus, incorporated in organic matter, from the North Sea to the Wadden Sea.

It follows from the foregoing paragraphs that part of the organic matter present in the Wadden Sea is formed in the North Sea. Another part will be synthesized by phytoplankton assimilation in the area itself. A rough estimate of this phytoplankton production has been made by means of chlorophyll determinations, which show that probably only 4–8% of the suspended organic matter consists of living phytoplankton. The highest phytoplankton concentrations occur in summer, the lowest in winter. The production of organic matter has been estimated from these data by assuming a daily growth of phytoplankton of 30% of its own weight. The production then appears to amount to 50,000–100,000 kg of organic matter per tide or 110 g/m^2/

year. This quantity is equal to 500–1000 kg P/tide. The supply of organic matter by the North Sea, which would amount to some 2000 kg P/tide, would therefore be of the same magnitude as the production of organic matter within the southwestern Wadden Sea itself.

VI. LITERATURE

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